A Survey of Thermodynamics and Transport Properties in Chemical Engineering Education in Europe and the USA

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Introduction

Thermodynamics and Transport Properties (TTP) is a central subject in the majority of chemical engineering curricula worldwide and it is thus of interest to examine how TTP is taught today in various countries. The contents and the organization of the courses reflect an understanding of reality (or philosophy) which often is not explicitly expressed. The discussion about different learning styles (cf., e.g., [1]) and their implication on teaching methods has also spurred us to investigate which methods are used for thermodynamics teaching, especially as thermodynamics often is regarded as a “difficult subject”. Our ultimate aim is that our results will help to improve chemical engineering education.

A survey of graduate thermodynamics education in the USA only was performed a few years ago by Visco et al. [2]. As far as we know no systematic study of the undergraduate thermodynamics education has been performed, at least in recent years. In the present study, a survey about TTP education in both undergraduate and graduate programs in Europe and the USA is presented. Answers from 136 universities from twenty different European countries and the USA were collected and used for this study. This study was performed under the auspices of the Working Party of Thermodynamics and Transport Properties of the European Federation of Chemical Engineering.

Methods

The survey was performed using a web based surveying system (MrInterview of the SPSS package) for which invitations were sent out to the universities. Several reminders were sent out but the answer frequency was varying significantly between the different countries (cf. Table 1).

Table 1. Number of universities/colleges per country that responded to the survey. No answers were obtained from any other country*).

Country	No of answers	Country	No of answers
Austria	1	Italy	5
Belgium	3	Netherlands	1
Bosnia and Herzegovina	1	Norway	1
		Portugal	5
Croatia	2	Russia	2
Denmark	2	Serbia	1
Estonia	1	Slovenia	2
Finland	4	Sweden	4
France	6	United Kingdom	7
Germany	28	USA	55
Greece	3		
Hungary	2		
		TOTAL	136

*)Countries from which no university / college responded are not shown.

Results

Of the universities that answered more than 70 % offer B.Sc. education, 65 % offer M.Sc. education and 55 % offer Ph.D. education. Most universities offer at least two courses of thermodynamics. Half of these are taught to chemical engineers exclusively whereas the rest are taught with other branches of engineering, mainly mechanical and / or process engineering.

Thermodynamics teaching in terms of quantity

The amount of thermodynamics taught has been analyzed both with respect to the number of courses and their size. The number of courses reported from each university is given in Table 2 where it can be seen that a majority of the universities in Europe report more than two courses each whereas in the USA the majority reports at most two courses. Hence, most of the following discussion will be based on the first two courses reported from each university.

Table 2 Number of thermodynamics courses reported at various universities

No of courses	% Europe	% USA
1	21	35
2	25	41
3	22	14
4	14	7
5	9	2
> 5	10	0

An issue that caused much confusion among the respondents was the definition of course size since no unambiguous measure of course length and work load exists. We have chosen to use the work load measured by the amount of full time study weeks per course, i.e., the intention is that if a course was expected to be studied as the only course during a given period, the value given should be the number of weeks that course was expected to fill the students time. If the student in a given program was expected to follow two courses at the same time, the week should be split between the courses according to their generated work load. In order to simplify the calculation for European universities we introduced a transformation from the European Credit Transfer System (ECTS) introduced with the Bologna agreement in Europe. 1.5 ECTS units equals approximately one week of work since one year usually contains approximately 40 study weeks and should correspond to 60 ECTS units. However, judging from the reactions of the respondents, such a measure is not familiar in many countries yet, and thus some care has to be exercised when interpreting the results regarding course lengths.

Table 3. Amount of thermodynamics (as full time study weeks) forming part of different course(s)

	Chem.Eng		PhysChem		Independ.		Other	
N:o of weeks	% USA	% Eur	% USA	% Eur	% USA	% Eur	% USA	% Eur
None	-	8	18	31	56	31	22	28
<3	2	8	37	34	4	20	41	21
3-7	43	26	32	23	24	20	24	32
8-12	9	32	7	6	4	15	11	14
13-18	13	15	4	6	4	8	2	5
19-24	9	5	2	1	4	4	-	1
>24	24	11	-	-	6	2	-	-

“Chem.Eng.” does not include physics, physical chemistry and similar fundamental courses but only (thermodynamics in) the applied chemical engineering courses.

In both regions, somewhat more than 40% spend at most 7 weeks on thermodynamics. In Europe the courses are generally less than 19 weeks whereas in the USA, one fifth spend more than one semester on thermodynamics. In general two sets of course lengths were observed, corresponding either to a full semester of full time studies or to quarter of a semester.

Table 4. Contents of thermodynamics course 1
(percent of total number of responses)

Topic	Central		Treated in some detail		Mentioned		Not part of the course	
	Eur	USA	Eur	USA	Eur	USA	Eur	USA
1st law	90	91	8	7	0	2	2	0
2nd law	88	80	10	11	1	2	1	7
Entropy	80	74	14	13	4	6	3	7
Molecular/Statistical interpretation of entropy	9	9	24	15	35	48	32	28
Free energy and quality of energy	44	43	22	26	22	19	11	13
3rd law and absolute entropy	26	33	21	18	35	35	18	33
Thermodynamic cycles	55	50	28	37	8	7	10	6
Heat expansion of solids and liquids	14	18	34	30	33	35	20	17
Equations of state	45	56	36	32	10	11	9	2
Phase equilibria	39	48	26	15	16	9	19	28
VLE	30	46	21	18	21	4	28	32
LLE	15	22	18	19	15	19	52	41
Heat transfer	9	7	19	11	20	39	52	43
Thermochemistry	21	9	16	20	6	30	56	41
Statistical thermodynamics	5	2	4	6	26	30	65	63
Molecular simulation	1	0	1	7	14	15	84	78
Kinetic theory of gases	8	0	15	9	32	22	45	68
Non-equilibrium thermodynamics	3	2	12	2	12	9	78	87
Thermodynamics for biological systems	4	0	3	6	16	37	78	58

Table 5. Contents of thermodynamics course 2 (percent of responses for course 2)

Topic	Central		Treated in some detail		Mentioned		Not part of the course	
	Eur	USA	Eur	USA	Eur	USA	Eur	USA
1st law	33	43	17	17	27	20	23	20
2nd law	36	46	14	20	25	17	25	17
Entropy	28	49	22	23	23	14	27	14
Molecular/Statistical interpretation of entropy	11	11	16	26	34	34	39	29
Free energy and quality of energy	36	34	19	37	22	14	23	14
3rd law and absolute entropy	19	11	25	23	22	29	34	37
Thermodynamic cycles	34	6	5	17	13	34	48	43
Heat expansion of solids and liquids	11	11	27	17	19	43	44	29
Equations of state	56	51	16	40	8	6	20	3
Phase equilibria	59	78	11	11	13	9	17	3
VLE	52	78	14	11	8	6	27	6
LLE	42	54	12	17	8	20	38	9
Heat transfer	22	6	12	17	14	20	52	56
Thermochemistry	36	29	17	31	6	23	41	17
Statistical thermodynamics	8	14	9	14	16	40	67	31
Molecular simulation	3	3	3	9	17	46	77	43
Kinetic theory of gases	8	3	8	14	23	26	61	57
Non-equilibrium thermodynamics	3	0	9	9	11	14	77	77
Thermodynamics for biological systems	3	3	8	17	6	31	83	49

In the first course, the first and second laws of thermodynamics as well as entropy are central in both regions (but 7% in the USA do not mention entropy!). Normally the statistical interpretation of entropy is mentioned as well as the third law and absolute entropy but not in significant depth. The second course is frequently more concentrated on phase equilibria. Both of these courses mainly consist of classical thermodynamics whereas the molecular interpretation often is touched upon. Statistical thermodynamics and molecular simulation as well as thermodynamics for biological systems are not central in any of the two courses neither in USA nor in Europe, but they are more frequently mentioned in the USA. Non-equilibrium themodynamics is equaly not part in any of the two first courses in any of the regions. These results are also reflected in the choice of course books, cf Table 6.

Table 6. The most popular textbooks for course 1 and 2
Books by the same (team of) authors have not been separated since the exact version often is unclear from the answers. There is a obvious difference in the choice of course books between the two continents even though a few books are popular in general, e.g., Smith, van Ness & Abbott.

Course 1	Europe	USA
Atkins (several versions)	18%	
Smith, van Ness & Abbott	11%	39%
Baehr et al.	8%	
Cengel (several versions)	4%	2%
Elliott & Lira		14%
Sandler		13%
Felder		11%
Koretsky		7%
Course 2		
Atkins (several versions)	23%	3%
Prausnitz (several versions)	11%	
Baehr	8%	
Smith, van Ness & Abbott	8%	43%
Gmehling	6%	
Sandler		14%
Koretsky		6%

Table 7. Time (in hours/course)used for different forms of teaching in course 1 in Europe [percent of answers; "(outside)" means "expected student work outside class", PBL = Problem Based Learning, cf. [1].]

Type	0 h	1-20 h	21-40 h	41-60 h	>60 h
Lectures (in class)	-	16	48	25	11
Lectures (outside)	16	39	28	11	5
Exercise classes	8	44	40	6	2
Exercise class (outside)	20	36	32	9	1
PBL etc. (in class)	70	25	5	-	-
PBL etc. (outside)	66	29	4	1	-
Home assign (in class)	41	44	8	6	1
Home assign (outside)	34	35	16	1	3
Laboratory classes	66	25	4	3	2
Lab classes (outside)	78	18	3	1	1

Table 8. Time used for different forms of teaching in course 1 in the USA (in hours/course), [Percent of answers, cf Table 7]

Type	0 h	1-20 h	21-40 h	41-60 h	>60 h
Lectures (in class)	-	11	54	30	6
Lectures (outside)	43	33	11	7	6
Exercise classes	11	59	22	7	-
Exercise class (outside)	48	35	13	2	2
PBL etc (in class)	26	56	13	4	2
PBL etc (outside)	44	32	15	7	2
Home assign (in class)	20	37	28	9	6
Home assign (outside)	11	28	20	20	20
Laboratory classes	83	15	-	2	-
Lab classes (outside)	83	13	4	-	-

Table 9. Time used for different forms of teaching in course 2 in Europe (in hours/course) [Percent of answers, cf Table 7]

Type	0 h	1-20 h	21-40 h	41-60 h	>60 h
Lectures (in class)	3	19	46	22	10
Lectures (outside)	18	35	25	3	5
Exercise classes	10	38	38	10	5
Exercise class (outside)	24	32	27	13	5
PBL etc (in class)	67	27	-	5	2
PBL etc (outside)	73	22	5	-	-
Home assign (in class)	48	40	8	3	2
Home assign (outside)	38	32	18	2	11
Laboratory classes	73	16	6	2	5
Lab classes (outside)	81	16	3	-	-

Table 10. Time used for different forms of teaching in course 2 in the USA (in hours/course) [Percent of answers, cf Table 7]

Type	0 h	1-20 h	21-40 h	41-60 h	>60 h
Lectures (in class)	-	16	48	25	11
Lectures (outside)	16	39	28	11	5
Exercise classes	8	44	40	6	2
Exercise class (outside)	20	36	32	9	1
PBL etc. (in class)	70	25	5	-	-
PBL etc. (outside)	66	29	4	1	-
Home assign (in class)	41	44	8	6	1
Home assign (outside)	34	35	16	1	3
Laboratory classes	66	25	4	3	2
Lab classes (outside)	78	18	3	1	1

Normally courses are centered around lectures and exercise classes with little or no laboratory work whereas home assignments are given in the vast majority of the courses. It can be noted that a rather large amount of time is used in class for home assignments and that problem based learning is twice as popular in course in the USA as in Europe.

Conclusions

In general, the fact that classical thermodynamics has not changed profoundly during the past decades is reflected in the invariability of the thermodynamics courses. The most popular textbook had its first edition 60 years ago and most other textbooks follow the same outline. More modern atomistic viewpoints are normally found in the (elective) later courses where they often are combined with statistical thermodynamics. This result may reflect how thermodynamics is needed and used in industry and an investigation of the use of thermodynamics within industry is also on-going within the Working Party. The results of that will be reported in the near future as well as a more detailed analysis of the education.

Since the response frequency is not extremely high, caution is needed when drawing conclusions from the material but we assume that some results are clear. Even though the results are quite similar for the USA and Europe a notable difference is the higher amount of problem based learning as well as the larger work with home assignments in the USA. Also there seems to be some more emphasis on atomistic understanding in American teaching.

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